ENERGY PRODUCTION FROM ASPEN IRRIGATED WITH GREY WATER: FINAL REPORT

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ABSTRACT

Aspen at sites in the Lincoln National Forest and in a wind tunnel/growth chamber at New Mexico State University were irrigated with fresh water in one treatment and with grey water in another treatment and the trees were monitored for growth. The diameter-at-breast-height and the plant height were the parameters of growth which were used. The results of these measurements were the basis for calculations of biomass change in each treatment. Similar measurements and calculations were applied to nearby clones of aspen which received only the naturally occurring precipitation. The growth rates in the treated clones were then compared to the growth rates in these control clones. The period of study was characterized by normal to considerably above normal precipitation. Under these conditions, those aspen treated with grey water enjoyed a growth advantage over both the fresh water treated and the control trees. Irrigation with fresh water showed no advantage over the controls. The juvenile trees which were in the wind tunnel/growth chamber and were irrigated with grey water achieved a greater growth rate than did those which were irrigated with fresh water. Potential problems with irrigation systems using grey water were noted and solutions indicated.

INTRODUCTION

There is the potential for both energy and sewage disposal problems to exist side-by-side at ranch, recreational and other remote sites. These sites are usually far from common energy sources so that wood is an attractive choice to supply energy. At the same time, edaphic and topographic conditions often limit their options for sewage disposal.

On-site trees can produce firewood and can use the nutrients which are contained in the liquid organic wastes from human habitation.

Aspen (Populus tremuloides, Michx), a common, relatively fast growing forest tree in the Rocky Mountains, has been shown by Bartos and Johnson (1978) to contain 6.2 to 9.3 kg./square meter of total aboveground biomass. They also found that the bole, bark, and branches comprised 91% of the aboveground biomass which contained 80 to 90 % of the elements N, P, Na, K, Ca, Mg, and Zn. Thus, removal of these trees for firewood would cause a nutrient drain from their site. Peterson, et. al.(1970), harvested 7.7 kg./square meter from a clone in Alberta. This biomass had an energy equivalent of 3630xE10 gram-calories/square meter.

Some human waste disposal systems, such as the Clivus-Multram system, separate the pathogenic portions of the waste from the liquid portion, or grey water. Others, such as the common septic-tank systems, produce an effluent from most of the pathogenic elements have been removed but which retain considerable amounts of plant nutrients.

These facts suggest that aspen, when irrigated with nutrient-rich grey waters, could enhance the energy production from a site while ameliorating the liquid waste disposal problem.

The overall objective of the study reported here was to determine the energy production levels, the importance of these levels relative to energy available to the sites, and practical methods of utilizing grey water to achieve these levels.

BACKGROUND

Aspen Growth

The peculiarities of growth of aspen are pertinent to understanding the significance of the results obtained in this study. Of particular interest is the fact that aspen roots form a relatively shallow mat with much intertwining. This provides the opportunity for nutrient transfer between individual ramets of a clone, both by root grafts and by mycorrhizal connections. Hansen and Dickson(1979) even found transfer of N, K, and water between Populus plants for which there was little, if any, possibility of root grafts or mycorrhizal connections. They presumed that the transfer took place through exudation from one root system and uptake by the other or by direct root-to-root contact. Certainly, the aspen involved in this study, where the root mass of many of the trees was contained by bedrock at shallow depths, possess roots with ample opportunity for such transfers.

Growth patterns of aspen are further influenced by the circumstances under which the stand was established in the first place. As pointed out by Jones and Trujillo(1975), the stocking, height growth, and standing crop will be different for a stand that developed after burning or clearcutting a predecessor aspen forest than it will be for one which was interspersed in a coniferous stand. Restocking by suckering after a disturbance is likely to be quite dense at first on an aspen forest site but little additional suckering will occur because of apical dominance and shading effects of the competition. For aspen in a predominently coniferous stand, on the other hand, regeneration is likely to be less than complete at first but suckering may continue for several years. While the stand densities may approach equality eventually, there will be a difference in the mix of dominant and codominant trees between to the stands so that growth of individual ramets will differ. They found, for instance, that there was a higher percentage of bole volume in overtopped trees, as compared to the dominant and codominant trees, in a high total volume stand than there was in the lower volume stands. At the same time, their height growth curves indicate that the overtopped trees in the high volume stand had experienced inferior height growth. Since some of the individuals measured in this study were overtopped, these conditions must be considered.

Diameter growth, another important measurement in this study, is subject to ambiguity in both attainment and interpretation. Jones and Trujillo(1975) note one case in which there was a marked reduction in diameter growth of all the trees in a plot for several years even though there was no climatic or other obvious peculiarity for that period. Diurnal variation in tree diameter is well documented (MacDougal, 1921; Fritts, 1958). Hydration and dehydration are known to change the diameter of plant stems. This effect is caused both by drought and by time of day. Kozlowski(1963) states that tree trunks usually undergo slight

shrinkage in the afternoon even in well watered soils because of a lag of water absorption behind transpiration. This effect is more noticeable in aspen and pine than in oak. Fritts(1960) concluded that changes in stem diameters due to hydration may be due to excess water (poor aeration) or insufficient water in drought periods, but these may be complicated even further by soil drainage, root distribution, degree of competition, crown size, or heredity. Further, excess sunshine and low velocity wind were considered to be inversely related to trunk diameter change.

There is substantial variation in growth between individual seedlings of aspen, other things being equal. This was shown by Okafo and Hanover(1978) who maintained constant ambient illumination, temperature and carbon dioxide levels for two species of aspen, and measured growth in terms of carbon dioxide respired. In trembling aspen they measured net photosynthesis per plant ranging from 14.3 to 55.5 mg. of carbon dioxide per hour.

Disease also is a factor in growth and ,especially, in terms of the final yield of wood. One prominent disease factor is decay. Hinds and Wingert(1977) identified the decay fungi responsible for 74% of the infections leading to culling and indicated that these accounted for 76% of the total cull. Trunk rot amounted to 66% and butt rot to 34% of the cull volume. Some decay, especially butt rot, was noted among the trees studied here.

Energy Value of Aspen Growth

Aspen can yield a greater volume of wood in a shorter period of time than most conifers, given favorable site conditions (Hinds and Wengert(1977). Bartos and Johnson(1978), using a total tree harvest method of sampling, found total biomass to range from 6 to 9 kg./square meter. Branches, bark and bole accounted for 87.4 to 94.3 percent of the total. Considering the leaves and current twigs as new growth, they concluded that about 3.6 percent of the total weight was new production.
Peterson, et. al.(1970) harvested 7.7 kg./square meter from a site in Alberta. The energy equivalent of this biomass was 3630xE4 g.cal./square meter. They also reported from other sources a range from 5.8 to 29 kg./square meter of production by aspen. The caloric values which they used to arrive the energy equivalent were 4720, plus or minus 4, g.cal./g. dry weight for the leaves, 4668, plus or minus 5, g.cal./g. dry weight for the branch wood and bark, and 4591, plus or minus 17, g.cal./g. dry weight for the trunk with bark. These values were obtained by calorimeter. They computed that the aboveground standing crop of aspen represented an accumulation of 3630xE4 g.cal./square meter, of which 84.3% was in the stems, 13.5% was in the branches, and 2.2% was in the foliage.

Fertilization of Aspen

Aspen have been found to respond significantly to irrigation by municipal waste water. Murphey and Bowier(1975) obtained this response by irrigating over a period of 10 years in which time they applied about 2030 cm. of effluent, 606 kg. of nitrogen, 465 kg. of chlorine, 114 kg. of potassium, 136 kg. of phosphorus, 435 kg. of calcium, 181 kg. of magnesium, and 272 kg. of sodium. The average annual increment in the trunk of the trees was about 1.7 cm. for the irrigated trees and about 0.6 cm. for the non-irrigated trees. van Cleve(1973) found similar results with young aspen, where a mixed fertilizer(N20,P5,K10,Ca10,Mg2) produced a 16% increase in volume increment and a 13% increase in diameter increment over controls during a three-year period.

Microenvironmental Effects on Growth

When comparing tree growth rates between sites the degree of microclimatic diversity between the sites needs to be assessed. Sharp vertical breaks at the edges of forest clearings are locations where shielding of adjacent surfaces from solar insolation occurs. At these locations latent and sensible heat fluxes tend to be lower and ground heat storage higher. Tuller(1973) found, in a mixed, but predominately Douglas fir stand, that exposure to direct beam solar radiation was the most important factor in determining these differences. He found that the north and east sides of a clearing were the warmest, while the south side remained cool and damp throughout the day and the western side was intermediate in microenvironmental effect. Variations to this general pattern are noted by Stage(1976), who defines a method for accounting for slope along with aspect. His regression equation was worked out for western white pine stands, and thus does not apply directly to aspen.

A factor helping to determine the productivity of a stand of trees is the amount of photosynthetically-active radiation (PAR) which the stand, especially in its shaded portions, sees. Zavitkovski (1982) measured less than 1% of PAR transmitted through a fully-foliated, dense stand, popular plantation. Similar leafless canopies transmitted only 50%. In the open he measured a maximum PAR of near 2000 micro-E/square meter-second on clear summer days. The average daily PAR for the growing season was 30-33 micro-E/square meter.

The annual radiation regime was approximated by Hutchison and Matt (1977) in a deciduous forest. While absolute amounts of radiation

at their east Tennessee site are probably not applicable to Rocky Mountain sites, the succession of radiation levels should be similar for other stands of deciduous trees. Maximum radiation was found to penetrate the forast in early spring. After leaf expansion, radiation diminished despite increases in solar elevations and insolation levels. After the summer solstice the decline in solar elevations and insolation levels was seen but when the leaves fell there was a slight increase in the amount of radiation penetrating the forest. Minimum insolation penetrated the forest around the winter solstice.

The evapotranspiration to be expected from aspen stands has been estimated to be from 46-61 cm. annually (Forest and Range Hydrology Handbook, 1959).

Fate of Nutrients in Soils

Van Cleve and Moore (1978), in a follow-up study to the one cited above (Van Cleve,1973), measured increases in the amounts of N,P,K, and Cl in the 0-30 cm. depth of an aspen root zone after the application of these elements over a 5-year period. They had applied totals of 777 kg/ha of N and K and 385 kg/ha of P. In general, this fertilization resulted in higher soil respiration and in increases in surface soil (0 to 15 cm.) organic matter content.

An indication of the movement of N and P, the nutrients arising from home waste disposal which are of the most concern, has been given by Sikora and Corey (1976). The soils which they studied were under septic tank disposal fields. They concluded that the probable N end products would depend upon the soils involved. For the silty clay loams they would expect a mixture of nitrate and ammonium forms of N with a possibility of decreasing total N because of denitrification. For clay loams they would expect the ammonium form to predominate. They expected the P to be immobilized in time.

Characteristics of Grey Water at Remote Sites

In general, sewage at remote sites is more fresh and at a higher temperature than ~~is~~ sewage at municipal plants. Grey water contains approximately 80 to 90 % of total organics, 60 to 70 % of total phosphorus, and 65 to 70 % of total nitrogen found in city sewage (Metcalf and Eddy, 1979). A synthetic grey water should meet the following specifications:

$$180 < BOD < 200 \text{ mg/l}$$
$$300 < COD < 360 \text{ mg/l}$$
$$22 < N_{total} < 23 \text{ mg/l}$$
$$8 < P_{total} < 13 \text{ mg/l}.$$

METHODS

Description of Sites

Four sites in the Lincoln National Forest in South-Central New Mexico were used to study the effects of the application of grey water to natural stands of aspen. At each site there were three treatments applied;viz.,GREY water, FRESH water,and unwatered, or CONTROL. The four sites, as pictured in Figures 1 through 4, were designated as AI, AII, B, and C. At each site the treatments were applied to five ramets for each treatment, with the exception of the CONTROL treatment at site C which consisted of three ramets. By the end of the study period one ramet had blown down in the FRESH treatment of site AII and one ramet had died in each of treatments AI FRESH and C GREY. A brief description of the sites is given in Table 1.

Table 1. Site Descriptions

SITE	ELEVATION	SOIL TYPE	ASPECT	POSITION
AI	2805m	Peso-Mescalero	SE	Lat.N32 53 Long.W105 45
AII	2805m	Peso-Mescalero	SE	Lat.N32 53 Long.W105 45
B	2760m	Peso-Mescalero	N	Lat.N32 54 Long.W105 45
C	2730m	Peso-Mescalero	SW	Lat.N32 58 Long.W105 44
Ponderosa	2380m	N/A	N	Lat.N32 52 Long.W105 39

The soil type, Peso-Mescalero, was dominated primarily by the Mescalero soils at these sites. These soils, occur commonly on the gently to strongly sloping and rolling ridge tops. They have a thin surface layer of very dark greyish-brown, stony, silty clay loam that is neutral in reaction. Their subsoil is a very dark greyish-brown, very cobbly silty clay loam or clay loam. This grades through a brown, very cobbly clay loam to the underlying fractured limestone bedrock at a depth ranging from 50cm. to 100cm. The stones and cobbles, which consist of limestone fragments, may comprise as much as 85 percent or more of the soil mass in the layers immediately above the underlying bedrock (Maker,et. al., 1972).

Figure 1. Aspen Site AI.

Figure 2.
Aspen Site AII.

Figure 3. Aspen Site B

Figure 4. Aspen Site C

All of the stands were mixed to some degree with Ponderosa Pine and White Fir, but site C was the most affected by the presence of these trees (primarily the White Fir). Sites AI and AII were most nearly what could be called pure Aspen stands (see Figures 1 through 4).

Description of Irrigation System

Figure 5 illustrates the irrigation system used. Four seepage wells per tree were installed at first but that number was doubled for most trees in order to obtain reasonable application times. In a few cases it was not possible to install the wells as deep as shown because of the bedrock.

Grey and fresh water were delivered to the wells by hose from barrels and tanks in which a low pressure was maintained by an air compressor. The amount of water applied was measured through Sparling meters.

Irrigations were scheduled for once each week in 1981 and for twice each week in 1982.

Description of Grey Water

The grey water used was synthesized by mixing commercial dog food and detergent with fresh water from the Town of Cloudcroft water system or with final effluent from the Town of Cloudcroft sewage disposal system. The effluent mixture was used in 1981 and the fresh water mixture was used in 1982. The effluent received post-treatment chlorination.

Analysis of Grey Water

The grey water was analyzed for total Kjeldahl nitrogen, nitrates, nitrites, ammonium nitrogen, phosphates, total suspended solids, and biochemical oxygen demand.

Growth Measurements

Diameter at breast height was measured with a caliper. The trees were marked at the measurement sites so that the measurements were made at the same site each time. Diameters were measured at or near sun-up to minimize and equalize shrinkage effects on the measurements. Heights were measured by triangulation using transits.

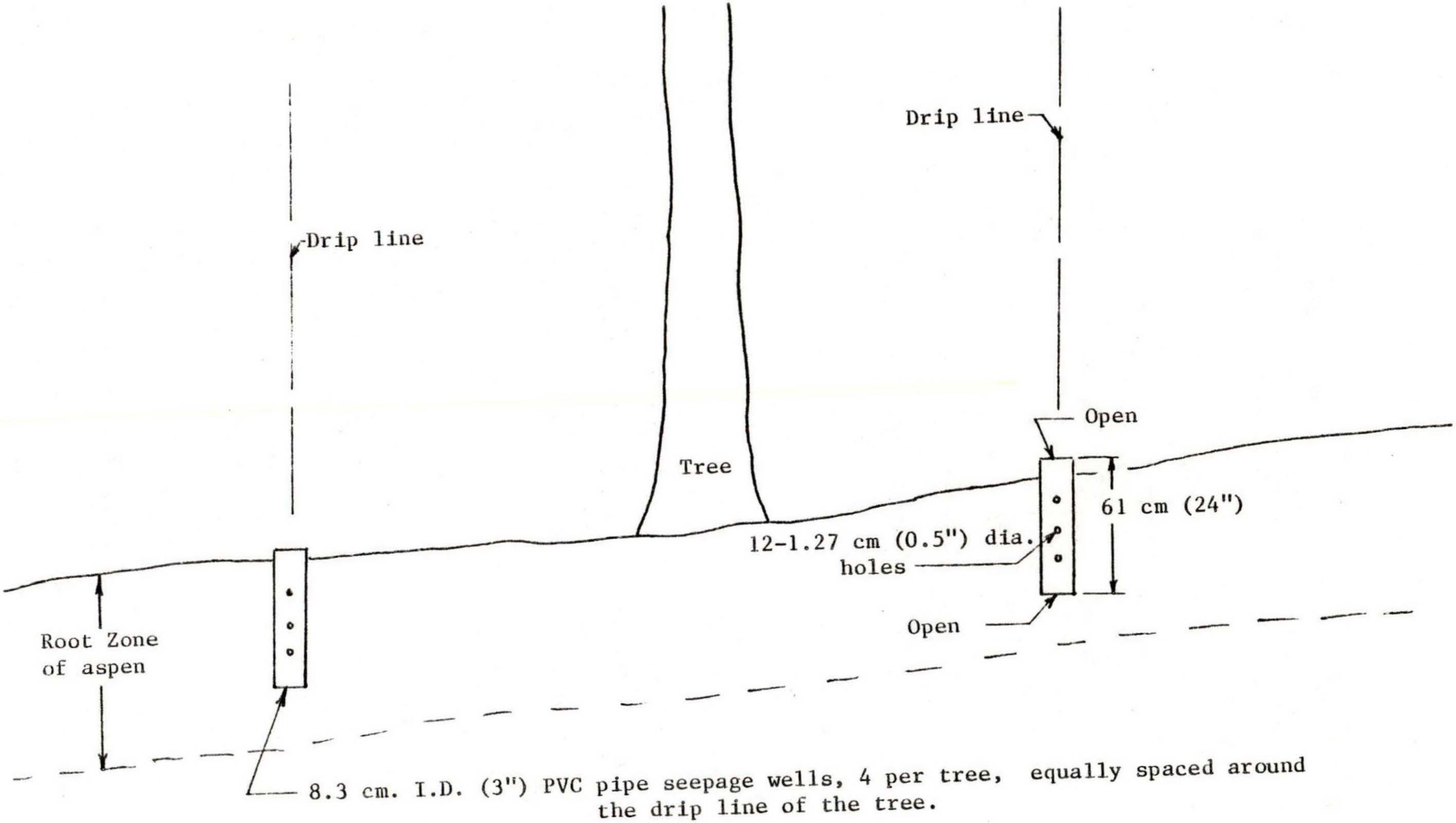

Figure 5. Irrigation system for applying grey and fresh water to aspen.

Microenvironmental Measurements

Solar radiation was measured with a recording pyranograph. Photosynthetically active radiation was measured with a quantum sensor. Wind speeds were taken with a totalizing anemometer. Gravimetric sampling was used to obtain soil moisture and nutrient levels. Soil temperatures were measured with thermocouples. Air temperature and humidty and barometric pressure were taken with a recording meteorograph.

A continuously monitoring microenvironmental station was established at a site approximately 12 km. from the treated sites. It is called Ponderosa in the above site descriptions.

Description of Juvenile Trees Grown in Wind Tunnel

Seedling aspen were placed in an atmospheric wind tunnel when they were approximately 5 months of age and their growth was monitored throughout the summer of 1982. Grey water and fresh water from the same mixes used in the forest were applied as randomized treatments to these trees. Height changes were used as the measures of growth.

Data Analysis

Growth responses to treatment were assessed by analysis of variance on randomized complete blocks with one-way classification. Increments of diameter at breast height and height were used as the measures of response. Biomass increments were computed from the DBH and height increments. These computations followed the procedures outlined by Jones and Trujillo(1975) with comparisons being made to values obtained by the methods given by Bartos and Johnson(1978). It was found that the latter method gave values of biomass which were higher for large trees and lower for small trees than those from the former method. The former method was used for the final evaluations since it allowed consideration of both DBH and height.
The formulae used to compute the biomass were:

$$\log 10 DWkg=1.028(DBH^2 x HT)-1.961 \text{ for bole wood, and}$$

$$\log 10 DWkg=0.981(DBH^2 x HT)-2.500 \text{ for bole bark,}$$

where DWkg= the dry weight, in kilograms,
DBH= the diameter at breast height, in centimeters, and
HT= the height in meters.

RESULTS

The results of an analysis of variance applied to change in diameter at breast height of the trees during the period from May 13,1981 to October 6,1982 are shown in Table 2.

Table 2. Growth in Diameter at Breast Height for the Whole Period

Site	Treatment	Growth in DBH,cm/day	Percent of Control
AI	Fresh	0.9436x(10)-3	100
	Grey	1.2402	131
	Control	0.9455	100
AII	Fresh	1.5747	115
	Grey	1.1123	81
	Control	1.3659	100
B	Fresh	0.4802	42
	Grey	0.7845	68
	Control	1.1511	100
C	Fresh	1.5178	105
	Grey	1.6750	101
	Control	1.6623	100

The F-score for treatment effects is 0.3856, which is not statistically significant.

The results of an analysis of variance applied to the changes in height of the trees during the period from May 13,1981 to October 6,1982 are shown in Table 3.

Table 3. Growth in Height for the Total Period

Site	Treatment	Height Change cm/day	Percent of Control (ave.)
AI	Fresh	0.050	151
	Grey	0.050	151
	Control	-0.011	NA
AII	Fresh	0.065	195
	Grey	0.057	172
	Control	0.033	99
B	Fresh	0.111	332
	Grey	0.031	92
	Control	0.087	260
C	Fresh	0.017	50
	Grey	0.041	123
	Control	0.025	76

The above values were arrived at from the following averages:

	Fresh	0.061	182
	Grey	0.045	134
	Control	0.033	100

The F-score for treatment effects was 1.351. This value should be compared to the tabular value of F of 1.76 ,with degrees of freedom of 2 and 6 and at the 25% level.

The results of an analysis of variance applied to changes in diameter at breast height of the trees during the growing season of 1981 are shown in Table 4a.

Table 4a. Growth in Diameter at Breast Height during 1981

Site	Treatment	Growth of DBH cm./day	Percent of Control
AI	Fresh	2.4707x(10)-3	118
	Grey	2.5317	121
	Control	2.0911	100
AII	Fresh	3.2614x(10)-3	102
	Grey	2.2743	71
	Control	3.1833	100
B	Fresh	1.6417x(10)-3	44
	Grey	1.4682	39
	Control	3.7680	100
C	Fresh	3.2063x(10)-3	105
	Grey	2.5914	85
	Control	3.0443	100

The F-score for treatment effects was 1.343. This should be compared to the tabular value for F of 1.76 for degrees of freedom of 2 and 6, at the 25% confidence level.

The results of an analysis of variance applied to change in diameter at breast height of the trees during the growing season of 1982 are shown in Table 4b.

Table 4b. Growth in Diameter at Breast Height during 1982

Site	Treatment	Growth of DBH cm/day	Percent of Control
AI	Fresh	1.1662 x(10)-3	108
	Grey	1.4058	130
	Control	1.0820	100
AII	Fresh	1.1139x(10)-3	83
	Grey	1.2249	92
	Control	1.3349	100
B	Fresh	0.2985x(10)-3	47
	Grey	0.9819	154
	Control	0.6368	100
C	Fresh	1.6908x(10)-3	102
	Grey	1.8949	114
	Control	1.6592	100

The F-score for treatment effects was 3.925. This should be compared to the tabular values for F of:

5.143 for d.f. of 2 and 6, at the 5% level, and
3.46 for d.f. of 2 and 6, at the 10% level.

The results of an analysis of variance applied to the changes in height of the trees during the two growing seasons, 1981 and 1982, are shown for comparison in Tables 5a and 5b. The values for 1981 were obtained by smoothing the data for that period by regression analysis using the slope of the regression line as the growth rate. The values for 1982 represent differences in heights between the beginning and end of the period.

Table 5a. Height Growth Rates for 1981

Site	Treatment	Height Growth Rate, cm/day	Percent of Control	Grey/Fresh %
AI	Fresh	0.068	48	
	Grey	0.129	91	190
	Control	0.141	100	
AII	Fresh	0.111	126	
	Grey	0.164	186	148
	Control	0.088	100	
B	Fresh	0.336	382	
	Grey	0.318	361	95
	Control	0.088	100	
C	Fresh	0.043	51	
	Grey	0.149	177	347
	Control	0.084	100	

The F-score for treatment effects was 1.435. This value should be compared to the tabular values of F of:

5.143 for d.f. of 2 and 6, at the 5% level, and
1.76 for d.f. of 2 and 6, at the 25% level.

Table 5b. Height Changes for 1982

Site	Treatment	Height Growth Rate, cm./day	Percent of Control	Grey/Fresh %
AI	Fresh	0.074	190	
	Grey	0.080	205	108
	Control	0.039	100	
AII	Fresh	0.041	13	
	Grey	0.104	32	254
	Control	0.321	100	
B	Fresh	0.279	377	
	Grey	0.189	255	68
	Control	0.074	100	
C	Fresh	0.311	109	
	Grey	0.102	36	33
	Control	0.285	100	

The F-score for treatment effects was 0.344 which is not statistically significant.

An analysis of variance was applied to the changes in height of the juvenile trees in the wind tunnel/growth chamber. The results are shown in Table 6.

Table 6. Height Changes for Juvenile Trees

Treatment	Replication	Height Change in cm.
Grey	1	3.1
	2	5.6
	3	7.2
	4	5.1
	5	3.9
	6	7.8
Fresh	1	-8.1
	2	-3.4
	3	4.5
	4	2.8
	5	4.7
	6	7.6

The average growth in the Grey Treatment was 5.4 cm., which was 419% of the average in the Fresh Treatment, 1.3 cm.

The analysis of variance yielded an F-score of 4.237. This value should be compared to the tabular value of F of 4.06, with degrees of freedom of 1 and 5, at the 10% level.

An indication of the amount of energy available to the aspen can be obtained by reference to Table 7. Therein are listed average amounts of insolation reaching the ground at the site Ponderosa on the clear days for all months except July and August of 1982, plus near-clear days of July and August. There were only two clear days in July and none in August. The insolation for the near-clear days was obtained by smoothing the pyranograph curves and integrating to find the area under the curve.

Table 7. Average Insolation at Ponderosa for Clear and Near-clear Days, in Langleys/day.

1981			
September	October	November	December
375	374	196	163
1982			
January	February	March	April
197	315	395	550
May	June	July	August
663	709	707	597

Total insolation for the two summers, 1981 and 1982, was 1234xE6 g.-calories per square meter.

The rainfall amounts at the sites during the growing seasons of 1981 and 1982 are given in Table 8.

Table 8. Rainfall at Sites

Site	Rainfall,mm.	Percent of Normal
1981		
AI and AII	401	144
B	350	126
C	278	100
1982		
AI and AII	331	119
B	238	86
C	268	96
Whole Period, 1981-1982		
AI and AII	732	312
B	588	106
C	546	98

Normal is considered to be the 37 year mean of rainfall for the months of June, July and August at the Cloudcroft weather station (USDA,1941).

The results of an analysis of variance applied to the percent changes in bole wood plus bole bark biomass of the trees during the period from May 13, 1981 through October 6, 1982 are shown in Table 9. Individual points for these data were obtained by the methods indicated by Jones and Trujillo (1975). Values for diameter-at-breast-height and tree height were from the solutions to the regression equations for these parameters for each tree. The regression equations were solved at days 1 and 775 of the time period.

Table 9. Growth of Bole Wood and Bole Bark for Total Period

Site	Treatment	Growth in Percent	Plot Weights, kg. Beginning	Growth
AI	Fresh	11.1	916	102
	Grey	13.0	606	79
	Control	6.3	551	35
AII	Fresh	12.9	692	89
	Grey	19.4	67	13
	Control	11.7	607	71
B	Fresh	6.9	594	41
	Grey	9.0	665	60
	Control	12.7	466	59
C	Fresh	27.3	77	21
	Grey	33.3	63	21
	Control	26.4	106	28

The F-score for the treatment effects was 2.653. This should be compared to the tabular value of F of 1.76 for degrees of freedom of 2 and 6 at the 25% level of confidence, and to the value of F of 3.46 for degrees of freedom of 2 and 6 at the 10% level of confidence.

When the above values are totaled by treatment the results in terms of percent growth are:

Fresh	11.1
Grey	12.4
Control	11.1.

When these growths rates are converted to the energy growth rates which they represent, the results are as shown in Table 10.

Table 10. Energy Growth in Bole Wood and Bole Bark for Total Period

Site	Treatment	Area square m.	Energy Growth calories/square m.
AI	Fresh	130	3.6xE6
	Grey	50	7.3xE6
	Control	80	2.0xE6
AII	Fresh	140	2.9xE6
	Grey	85	0.7xE6
	Control	80	4.1xE6
B	Fresh	30	6.3xE6
	Grey	30	9.2xE6
	Control	70	3.9xE6
C	Fresh	30	3.2xE6
	Grey	45	2.1xE6
	Control	20	6.4xE6
Mean for the Grey Treatments only			4.82xE6

The amounts of water and chemical constituents applied in the grey water treatments during the summers of 1981 and 1982 are shown in Tables 11a and 11b.

Table 11a. Chemical Constituents Added per Ramet during 1981.

CONSTITUENT	SITE			
	AI	AII	B	C
Nitrogen as N, gm.	27.7	27.7	26.6	26.6
Phosphorus as P, gm.	15.8	15.8	15.9	15.9
Biochemical Oxygen Demand, gm.	287	287	372	372
Total Suspended Solids, gm.	60	60	88	88
Water, liters	984	984	984	984
Nitrogen as NO3, gm.	3.5	3.5	6.4	6.4
Nitrogen as NH4, gm.	0.3	0.3	0.5	0.5
TKN as N, gm.	26.9	26.9	25.2	25.2

Table 11b. Chemical Constituents Added per Ramet during 1982.

CONSTITUENT	SITE			
	AI	AII	B	C
Nitrogen as N, gm.	24.1	25.3	21.2	21.2
Phosphorus as P, gm.	15.3	14.1	14.5	15.3
Biochemical Oxygen Demand, gm.	394	388	387	421
Total Suspended Solids, gm.	246	246	266	260
Water, liters	1590	1590	1514	1590
Nitrogen as NO3, gm.	14.0	15.0	11.1	11.1
Nitrogen as NH4, gm.	2.4	3.0	2.0	2.5
TKN as N, gm.	20.9	21.9	18.7	18.7

DISCUSSION OF RESULTS

Growth for the Overall Period, 1981 and 1982

By reference to Table 9 it can be seen that the trees treated with grey water enjoyed an advantage in growth as measured by potential fuel biomass production. Those trees which were irrigated with fresh water showed no increase in production over the trees which received only rain water. These results were statistically significant only at a low level of confidence (25%). To place these results in perspective it is well to characterize this time period as to precipitation. As seen in Table 8 the precipitation for the period varied from 98% of normal at site C to 312% of normal at the A sites. Thus the 1981-1982 seasons represent "wet" years and the advantages of irrigation should be less obvious than in other years.
The average energy value for the growth in the area treated with grey water was 4.83xE6 gm.-calories per square meter as shown in Table 10. Over the time that this growth was occurring average insolation measurements indicate that the area received approximately 1234xE6 gm.-calories per square meter (see Table 7). Therefore, the efficiency of utilization of solar energy was 0.39 percent. The above energy values were computed on the basis of 4591 gm.-calories per gram dry weight for the trunk with bark (Peterson, et.al.,1970).

Growth by Years

The two parameters of growth, height and diameter-at-breast-height, showed considerable variability by year; therefore, they will be discussed seperately.Reference is made to Tables 4a, 4b, 5a, and 5b.

DBH:

The growth in DBH in the ramets treated with fresh water was consistent between the years except for a decreased rate of growth advantage over the control sites at sites AI and AII in 1982. This decrease was possibly due to a nutrient drain or a lack of oxygen since the A sites received a large amount of precipitation.

The growth advantage in DBH in the ramets treated with grey water increased at all sites in 1982. There was a dramatic increase at site B in 1982, possibly due to delayed release of nutrients. Another possible cause is the greater availability of nitrogen in the nitrate form during 1982 (see Tables D8a and D8b).

Absolute growth rates in DBH decreased at all of the sites in 1982. Less precipitation fell at all sites in 1982 than in 1981.

HEIGHT:

The growth in height in the ramets treated with fresh water was consistent between the years only at site B. There were dramatic increases in growth advantage over the control treatments at sites AI and C, and a dramatic decrease at site AII.

The advantage in height growth in the ramets treated with grey water increased dramatically at site AI, decreased dramatically at sites AII and C and decreased modestly at site B, between the years.

Height growth rates at the control sites increased at sites AII and C, but decreased at sites AI and B.

Growth in height in the juvenile trees in the wind tunnel / growth chamber showed a dramatic advantage for those watered with grey water over those who received fresh water.

Several characteristics of the aspen growth under irrigation are noted from the above facts.

1. Increase growth in DBH appears to be inverse to increase in height growth rate.
2. Aspen which were watered only by precipitation experienced more consistent growth in diameter-at-breast-height but a large amount of natural variation in height. This gives emphasis to the findings of Okafo and Hanover (1978).
3. The juvenile aspen responded well to irrigation with grey water.

CONCLUSIONS

The naturally occurring differences between sites at which aspen grow should be taken into account when deciding whether or not irrigation with grey water would be beneficial at a particular site. The indications from the results cited here are that irrigation with grey water will indeed increase the production of wood for fuel. This is especially true in those years when precipitation is short enough that full advantage may be taken of the benefits of both the water and the nutrients being added.

The response to irrigation by grey water can be expected to be most dramatic in the smaller trees in height growth. However, the larger trees are better able to produce biomass, hence, will produce more usable energy. Similarly, greater response can be expected from dominant ramets than from others. In order to achieve maximum response it would be well to avoid irrigating those ramets which are diseased (Hinds and Wengert,1977).

Systems for irrigating with grey water should be carefully planned to make certain that the water will actually reach the intended ramets. Generally this will mean that the water must be applied in a relatively shallow zone in the soil with as much areal coverage as possible. This arrangement will help to insure that the nutrients will reach the intended ramets primarily even if root grafts and mycorrhizal connections exist (Hansen and Dickson,1979).
Attention must be given to making sure that the grey water does not become available for exposure to humans or animals, since the absence of pathogens from the grey water cannot be guaranteed. Precautions need to be taken in the design of the irrigation system for grey water to anticipate clogging of the soil pores and/or the irrigation system orifices.

Evaluation of the biomass changes during growth are best evaluated using expressions which include both DBH and height as arguments because of the apparent inverse relationship between these two parameters.

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